PHYSICAL TEST OF STAINLESS STEEL 316 BETWEEN DIFFERENT MANUFACTURES

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ABSTRACT

Tubing is usually used in crude oil instrumentation system, natural gas, industrial gas, and food industry. With the involvement of the oil and gas tubing, many products would be affordable to be manufactured and the costs to convey these products to market would be economical. Products marking in the tubes include manufacture name or brand, specification number and grade on tubes. Different manufacture has different material characteristic although it is of the same grade. Thus, this research is perform to determine the modulus of elasticity, tensile strength and yield strength of stainless steel 316 from different manufactures. Comparison of modulus of elasticity, tensile strength and yield strength of stainless steel 316 from different manufactures are made. By appropriate scaling, load and displacement data that were obtained in the test were calibrated and cross-plotted to give an engineering stress-strain curve for each and every specimen. From the Universal Tensile Machine, graph of force versus displacement is generated. From the stress-strain curve, values of modulus of elasticity, ductility, tensile strength and yield strength for Sample A were 12869.22 MPa, 44.04501932%, 548 MPa, and 332.7333 MPa respectively. And for values of modulus of elasticity, ductility, tensile strength and yield strength for Sample B were 12722.43 MPa, 36.09215017%, 536.6667 MPa, and 314 MPa respectively. From the values that were obtained, the material characteristics of Sample A are found to be stronger than Sample B.

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LIST OF ABBREVIATIONS

A_0	original cross sectional area
e/ϵ	engineering strain
$\Delta l/Lf - Lo$	elongation of the gage length of the specimen
Lo	original gage length
M	meter
Mm	millimetre
P	load
S/σ	engineering stress
r1	internal diameter
r2	outer diameter
TS	tensile strength
YS	yield strength
E	modulus of elasticity
MPa	megapascal
%EL	ductility

1 INTRODUCTION

1.1 *Motivation and statement of problem*

Tubing is usually used in crude oil, instrumentation system, natural gas, industrial system, and food industry. With the involvement of the oil and gas tubing, many products would be affordable to be manufactured and the costs to convey these products to market would be economical. Many industries using stainless steel tube in their plant. Usually is in the appliances they used in their plant such as in heat exchanger. The effectiveness of the tubes is partially feature by their practicality and safety. As tubes are a competent means for the transportation of oil and gas, their important and safety have concerned a great deal of interest. It is necessary that some knowledge of the maximum pressure load of tubing can support without leakage or catastrophic fracture be acknowledgeable to the designer and user for a gas installation system to be used safely. Therefore, an important deliberation in the design for safety and integrity evaluation of tubing is the accuracy prediction of their burst pressure has been stated by Zhu & Leis (2012). Various materials are focus to forces or loads for examples the aluminum alloy is constructed on an airplane wing and the stainless steel on installation of gas pipeline system. In such conditions it is required to identify the feature of the materials and to design the member from which it is made therefore to facilitate whichever consequential deformation will not be excessive and fracture will not happen. The mechanical performances of material indicate the relationship between its response or deformation to an applied load or force. Significant mechanical properties are strength, hardness, ductility, and stiffness.

Various parties (e.g., producers and consumers of materials, research organizations, government agencies) that have dissimilar significant have concern about mechanical properties. Thus, it is essential that there be some regularity in the technique in which tests are conducted, and in the analysis of their results. This regularity is accomplished by using standardized testing methods. Professional societies are usually corresponding to the establishment and publication of these standards. The most active organization in the United States is the American Society for Testing and Materials (ASTM). Their Annual Book of ASTM Standards (http://www.astm.org) consists of a lot of volumes, which are issued and updated annually; a large number of these standards associate to mechanical testing methods. One of the most general mechanical stress-strain tests is carry out in tension. The tension test can be used to ascertain several mechanical properties of materials that are significant in design. Usually in fracture, a specimen is deformed with a gradually rising tensile load that is applied uniaxially along the long axis of a specimen. These mechanical explanations have been explained by Callister & Rethwisch (2008).

One of the importance on testing and evaluation of tube performance is the increasing complexity of tubing systems. The stress at the maximum on the engineering stress-strain curve is the tensile strength. This relates to the maximum stress that can be continued by a structure in tension; if this stress is applied and maintain, fracture will result. It also can determine the exact limits of component's design because many companies do not have specialized pressure testing facilities of their own. Product marking is only including manufacture name or brand, specification number and grade on tubes. Different manufacture has different material characteristic although it is the same grade.

1.2 Objectives

The following are the objectives of this research:

- To determine modulus of elasticity of stainless steel 316 from difference manufacture.
- To determine tensile strength and yield strength of stainless steel 316 from difference manufacture.
- Comparison of modulus of elasticity, tensile strength and yield strength of stainless steel 316 from difference manufacture.

1.3 Scope of this research

The following are the scope of this research:

i) Tensile test is one of the tests to know the characteristics of materials.

ii) Universal tensile machine is one of the equipment to tests the tensile strength.

iii) With the specimens of 316 stainless steel with tube outer diameter 3/8" x 0.035" wall thickness.

iv) Universal tensile machine speed test is 5 mm/min.

1.4 Main contribution of this work

The following are the contributions in this paper:

- After doing this research, data obtained has indicates that different tubing has difference material characteristics although it has the same outer diameter and wall thickness.
- In the market there are various stainless steel with different grade and there are varieties of material properties. Between the manufactures there are also different values of material characteristics so no actual value are available.

1.5 Organisation of this thesis

The structure of the reminder of the thesis is outlined as follow:

Chapter 2 presents review of literature from previous study. When doing a testing, the selections of suitable tubing are important for compatibility of the tubing with the media to be connected. Stainless steel tubing have many grades that differ from every grade is their component elements. Stainless steel 316 is one of the austenitic stainless steel. One of the tests to know the material characteristics is tensile test. From the stress-strain curve, we can determine their material characteristics.

Chapter 3 consists of materials and methods used in this paper. Specimens used are from Sample A and Sample B that is stainless steel 316 tubes with outer diameter 3/8" and wall thickness is 0.035" with 6 meter length. Tensile test is the method used in this research.

Chapter 4 presents results from Universal Tensile Machine that is graph force versus displacement from 15 samples of Sample A and 3 samples of Sample B. Then these graph than normalized to stress-strain curve. From the stress-strain curve, their material characteristics were obtained and this paper also calculated their ductility.

Chapter 5 draws together a summary of the thesis and outlines the future work which might be derived from the model developed in this work.

2 LITERATURE REVIEW

2.1 Overview

This chapter presents review of literature from previous study. When doing a testing, the selections of suitable tubing are important for compatibility of the tubing with the media to be connected. Stainless steel tubing have many grades that differ from every grade is their component elements. Stainless steel 316 is one of the austenitic stainless steel. One of the tests to know the material characteristics is tensile test. From the stress-strain curve, their material characteristics were determined.

2.2 Introduction

This chapter contains review of literature from past study. It contains types of tubes that discussed about tubing selection, stainless steel described about the families of stainless steel, austenitic stainless steel and characteristic of stainless steel. Last subchapter is about tensile test.

2.3 Types of Tubes

2.3.1 Tubing Selection

When doing a testing, the selected tubing should similar to the tubing normally used in industries. The involvement of special selection or treatment should be avoided. If tubing used in industries not easy to get to, specifics recommended by fitting manufacturers, or to ASTM or other applicable standards for tubing can also be bought. These recommendations have been made by Callahan (1998).

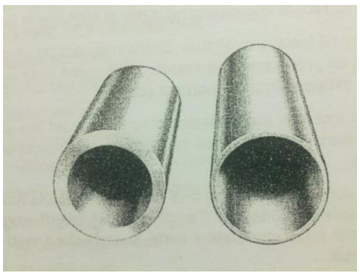

Figure 2-1: Thick and thin wall stainless steel tubing.

Parker Hannifin Corporation (2010) stated that the most significant deliberation in the selection of suitable tubing for any application is the compatibility of the tubing material with the media to be connected. Table 2-1 lists common materials and their associated general application. Table 2-1 also lists the minimum and maximum operating temperature for the various tubing materials.

Table 2-1: Lists common materials and their associated general application.

Tubing Material	General Application	Recommended Temperature Range
Stainless Steel (Type 316)	High Pressure, High Temperature, Generally Corrosive Media	-425°F to 1,200°F (-255°C to 605°C)
Carbon Steel	High Pressure, High Temperature Oil, Air, Some Specialty Chemicals	-20°F to 800°F (-29°C to 425°C)
Copper	Low Temperature, Low Pressure Water, Oil, Air	-40°F to 400°F (-40°C to 205°C)
Aluminium	Low Temperature, Low Pressure Water, Oil, Air, Some Specialty Chemicals	-40°F to 400°F (-40°C to 205°C)
Monel® 400	Recommended for Sour Gas Applications Well Suited for Marine and General Chemical Processing Applications	-325°F to 800°F (-198°C to 425°C)
Hastelloy®C-276	Excellent Corrosion Resistance to Both Oxidizing and Reducing Media and Excellent Resistance to Localized Corrosion Attack	-325°F to 1000°F (-198°C to 535°C)
Carpenter® 20	Applications Requiring Resistance to Stress Corrosion Cracking in Extreme Conditions	-325°F to 800°F (-198°C to 425°C)
Inconel® Alloy 600	Recommended for High Temperature Applications with Generally Corrosive Media	-205°F to 1200°F (-130°C to 650°C)
Titanium	Resistant to Many Natural Environments such as Sea Water, Body Fluids and Salt Solutions	-75°F to 600°F (-59°C to 315°C)

2.3.2 Stainless steel

Basically, stainless steel is an alloy of steel with a minimum of 11% chromium and more than 50% iron in it. It is highly strain, corrosion resistant and rust resistant that requires minimum maintenance. Some of these properties can be modified by adding metals like molybdenum, titanium, nickel, etc. in the substance of stainless steel which will gives increase to changes in its mechanical and physical properties. Because of their changes, there is hundreds of stainless steel grades can be created and used for a variety of function. Because of the features of stainless steel, most of industries used stainless steel tubes in gas installation system. As explained by Jadhav (2010).

As described in Atlas Steels Australia (2013), chemical formula for stainless steel grade 316 are Fe, <0.03% C, 16-18.5% Cr, 10-14% Ni, 2-3% Mo, <2% Mn, <1% Si, <0.045% P, and <0.03% S. Grade 316 is the standard molybdenum- bearing grade, second in importance to 304 amongst the austenitic stainless steels. The molybdenum gives 316 better overall corrosion resistant properties than Grade 304, particularly higher resistance to pitting and crevice corrosion in chloride environments. It has excellent forming and welding characteristics. It is readily brake or roll formed into a variety of parts for applications in the industrial, architectural, and transportation fields. Grade 316 also has outstanding welding characteristics. Post-weld annealing is not required when welding thin sections. Grade 316L, the low carbon version of 316 and is immune from sensitisation (grain boundary carbide precipitation). Thus it is extensively used in heavy gauge welded components (over about 6mm). Grade 316H, with its higher carbon content has application at elevated temperatures, as does stabilised grade 316Ti. The austenitic structure also gives these grades excellent toughness, even down to cryogenic temperatures.

One of the stainless steel type is currently being used as most important structural alloys in complicated nuclear systems and other dangerous and significant fields, where they are often exposed to complex thermo-mechanical loading histories is called austenitic stainless steel. In detail, many stainless steel elements are subjected throughout their manufacture, while in service or because of an accident, to complicated loading positions which can increase to multiaxial stress condition, strain-rate excursions covering numerous series of magnitude, unloading, reversed loading and cyclic loading. Correct information, understanding and description of the resulting non-conventional material feature are then demand for the safe and economic use of these structures. These explanations have been stated by Eleiche, Albertini & Montagnani (1985).

2.3.2.1 The Families of Stainless Steels

As discussed in Atlas Steels Australia (2013), stainless steels are iron-based alloys containing a minimum of about 10.5% chromium; this forms a protective self-healing oxide film, which is the reason why this group of steels has their characteristic "stainlessness" or corrosion resistance. The ability of the oxide layer to heal itself means that the steel is corrosion resistant, no matter how much of the surface is removed. This is not the case when carbon or low alloy steels are protected from corrosion by metallic coatings such as zinc or cadmium or by organic coatings such as paint.

Although all stainless steels depend on the presence of chromium, other alloying elements are often added to enhance their properties. The categorisation of stainless steels is unusual amongst metals in that it is based upon the nature of their metallurgical structure - the terms used denote the arrangement of the atoms which make up the grains of the steel, and which can be observed when a polished section through a piece of the material is viewed at high magnification through a microscope. Depending upon the exact chemical composition of the steel the microstructure may be made up of the stable phase’s austenite or ferrite, a "duplex" mix of these two, the phase martensite created when some steels are rapidly quenched from a high temperature, or a structure hardened by precipitated micro- constituents.

The relationship between the different families is as shown in Figure 2-2. A broad brush comparison of the properties of the different families is given in Table 2-2 and Table 2-3.

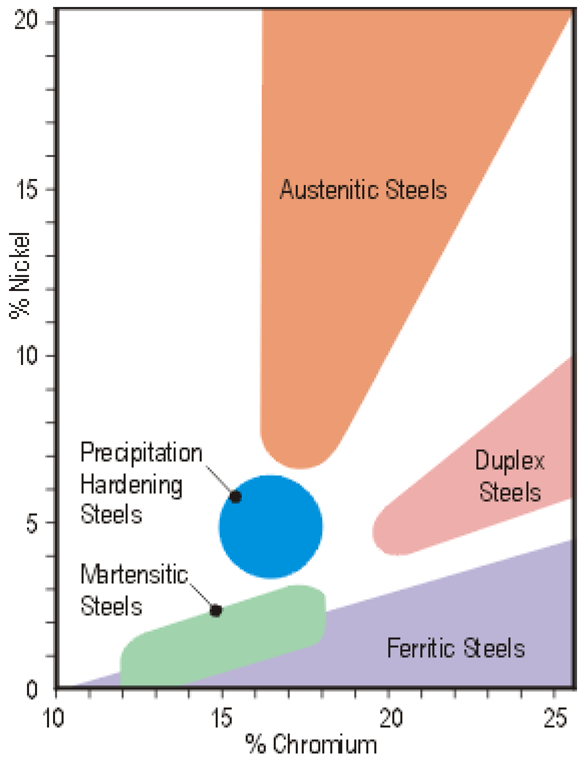

Figure 2-2: Families of stainless steels.

2.3.2.2 Austenitic Stainless Steels

This group contains at least 16% chromium and 6% nickel (the basic grade 304 is referred to as 18/8) and range through to the high alloy or "super austenitics" such as 904L and 6% molybdenum grades. Additional elements can be added such as molybdenum, titanium or copper, to modify or improve their properties, making them suitable for many critical applications involving high temperature as well as corrosion resistance. This group of steels is also suitable for cryogenic applications because the effect of the nickel content in making the steel austenitic avoids the problems of brittleness at low temperatures, which is a characteristic of other types of steel.

The relationship between the various austenitic grades is shown in Figures 2-3.

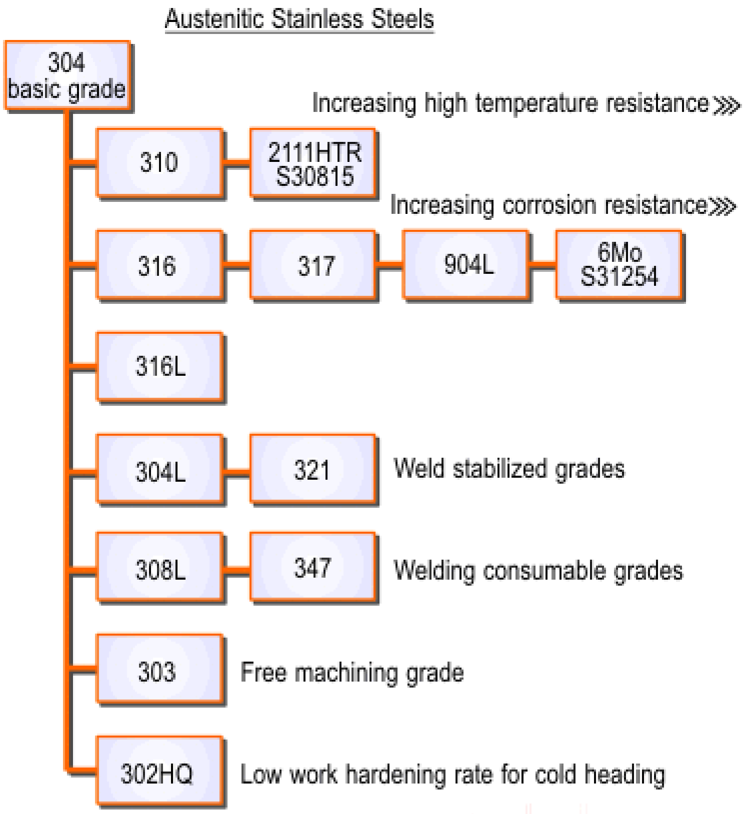

Figure 2-3: The Austenitic Stainless Steels.

2.3.2.3 Characteristics of Stainless Steels

The characteristics of the broad group of stainless steels can be viewed as compared to the more familiar plain carbon "mild" steels. As a generalisation the stainless steels have:

- Higher work hardening rate
- Higher ductility
- Higher strength and hardness
- Higher hot strength
- Higher corrosion resistance
- Higher cryogenic toughness
- Lower magnetic response (austenitic only)
- Must retain corrosion resistant surface in the finished product.

These properties apply particularly to the austenitic family and to varying degrees to other grades and families. These properties have implications for the likely fields of application for stainless steels, but also influence the choice of fabrication methods and equipment.

Table 2-2: Comparative Properties of stainless steel families.

Alloy Group	Magnetic Response[1]	Work Hardening Rate	Corrosion Resistance[2]	Hardenable
Austenitic	Generally No	Very High	High	By Cold Work
Duplex	Yes	Medium	Very High	No
Ferritic	Yes	Medium	Medium	No
Martensitic	Yes	Medium	Medium	Quench & Temper
Precipitation Hardening	Yes	Medium	Medium	Age Harden

1 = Attraction of steel to a magnet. Note some grades can be attracted to a magnet if cold worked.

2= Varies significantly within between grades within each group e.g. free machining grades have lower corrosion resistance, those grades higher in molybdenum have higher resistance.

Table 2-3: Comparative Properties of stainless steel families.

Alloy Group	Ductility	High Temperature Resistance	Low Temperature Resistance[3]	Weldability
Austenitic	Very High	Very High	Very High	Very High
Duplex	Medium	Low	Medium	High
Ferritic	Medium	High	Low	Low
Martensitic	Low	Low	Low	Low
Precipitation Hardening	Medium	Low	Low	High

3= Measured by toughness or ductility at sub-zero temperatures. Austenitic grades retain ductility to cryogenic temperatures.

2.4 Tensile test

One of the most significant of all materials test is tensile test. The information from this test is more accurate and gives more information on the strength of the materials. It is particularly suitable for steel of low carbon content (0.12-0.25%). In construction of steels, low carbon steel is the most significant and is used in the manufacture of cars, ships and bridges.

Gedney (2002) have described that a graphical description of the quantity of deflection under load for a given material is called the stress-strain curve as figure below. Engineering stress (S) is calculated by dividing the load (P) at any provided time by the original cross sectional area (A_o) of the sample.

$$S = P/A_O \qquad (2\text{-}1)$$

Engineering strain (e) is calculated by dividing the elongation of the gage length of the specimen (Δl) by the original gage length (l_o).

$$e = \Delta l/l_o = (l-l_o)/l_o \qquad (2\text{-}2)$$

The stress-strain curve feature of the shape and magnitude depend on the type of metal being tested. In figure below, point A shows the proportional limit of a material. Permanent deformation occurs when a material loaded in tension beyond point A even when the load is removed. Point B correspond the offset yield strength, and is found by constructing a line X-B parallel to the curve in the elastic region. Offset a strain amount O-X, which is typically 0.2% of the gage length for metals, is line X-B. Point C stands for the yield strength by extension under load (EUL), and can be found by constructing a vertical line Y-C. Offset a strain quantity O-Y, which is typically 0.5% of gage length, is line Y-C. Point D represents the tensile strength or peak stress. Depicted as strain and it shows the total elongation or the quantity of uniaxial strain at fracture is at point Z.

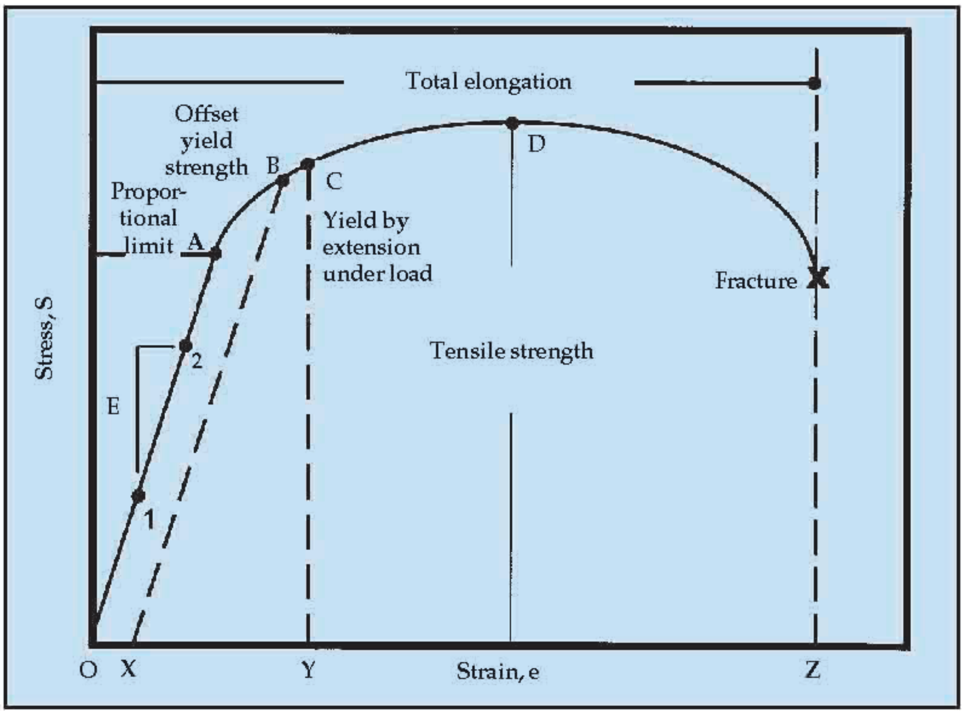

Figure 2-4: Stress-strain curve.

Modulus of elasticity as in The OHIO State University (n.d) defines as the ratio of stress to strain during elastic deformation when material is under uniaxial tension. Also known as Young's modulus. As in Granta (2011), yield strength often identify with the 0.2% offset, that is, the stress at which the stress- strain curve for axial loading deviates by a strain of 0.2% from the linear-elastic line as shown in Figure 2-4 (this 0.2% offset point is also associated with plastic strain). The ultimate (tensile) strength is the maximum engineering stress (applied load divided by the original cross-sectional area of the specimen) in a uniaxial stress-strain test.

Majority ASTM or same test methods need a shaped specimen that focuses the stress within the gage length. If the specimen is wrongly machined, it may have fracture outside the gage length, resulting in strain errors was discussed by Gedney (2002).

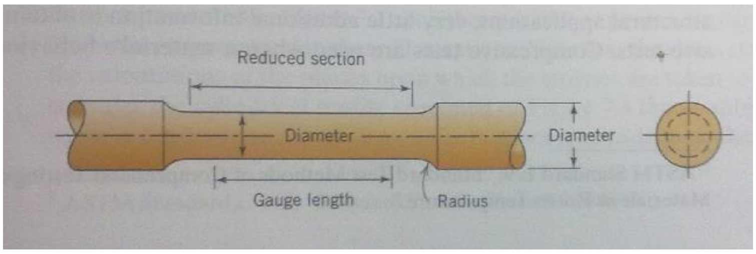

Figure 2-5: A standard tensile specimen with circular cross section.

2.5 Summary

This chapter contains review of literature from past study. It contains types of tubes that discussed about tubing selection, stainless steel described about the families of stainless steel, austenitic stainless steel and characteristic of stainless steel. Last subchapter is about tensile test.

3 MATERIALS AND METHODS

3.1 Overview

This chapter consists of materials and methods used in this paper. Specimens used are term as Sample A and Sample B that is stainless steel 316 tubes with outer diameter 3/8” and wall thickness is 0.035” with 6 meter length. Sample A and Sample B are stainless steel 316 tubes manufactured by different company. Tensile test is the method used in this research.

3.2 Introduction

This chapter described materials and methods used in the research. Subchapters are covers specimens, Universal Tensile Machine and data collection.

3.3 Tensile Test

Before testing any specimen, its dimensions, especially its diameter and length, was carefully measured. It is then loaded in the Universal Tensile Machine, at constant cross-head speed at 5 mm/min, unloaded, carefully removed from the setup and remeasured.

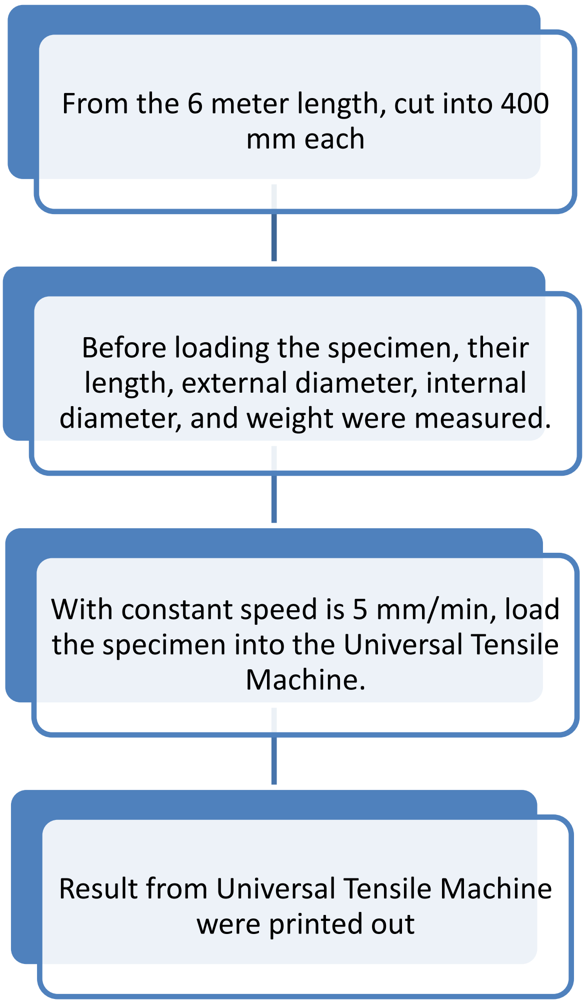

Figure 3-1: Illustrate the Research Design.

3.3.1 Specimens

Udomphol (n.d.) explained that a standard specimen is equipped in a around or a square section along the gauge length as represent in figure 3-2 a) and b) respectively, depending on the standard used. Both ends of the samples should have enough length and a surface circumstance such that they are firmly gripped during test. The initial gauge length Lo is standardized (in some countries) and differs with the diameter (Do) or the cross-sectional area (Ao) of the specimen as listed in Table 3-1. If the gauge length is too long it will cause the percentage of elongation may be underestimated in this case.

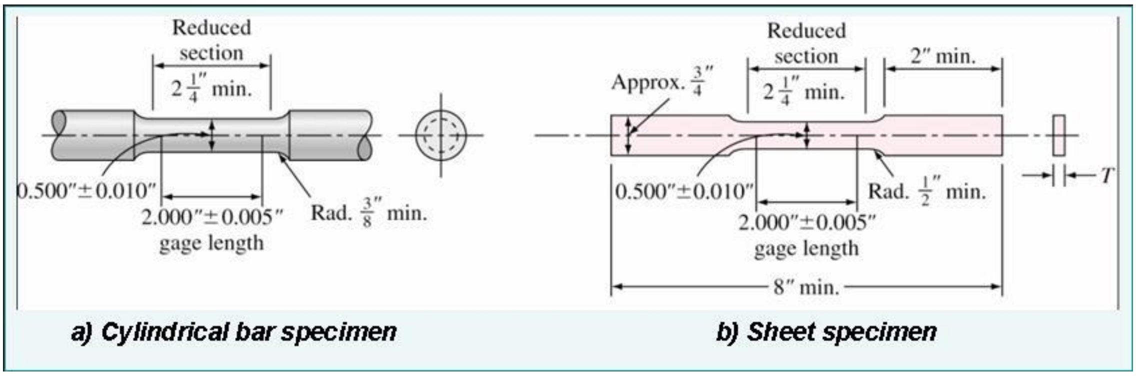

Figure 3-2: Standard tensile specimens

Table 3-1: Dimensional relationships of tensile specimens used in different countries

Type specimen	United State (ASTM)	Great Britain	Germany
Sheet ($L_o/\sqrt{A_o}$)	4.5	5.65	11.3
Rod ($L_o/\sqrt{D_o}$)	4.0	5.0	10.0

In this research, samples used are stainless steel 3/8 inch tubing with wall thickness 0.035 inch from Sample A and Sample B. Each manufacturer has 6 meter length tubing. From 6 meter, it is cut into 400 mm. Sample A have 15 samples and Sample B has 3 samples which look like Figure 3-3. Before loading into Universal Tensile Machine, their dimensions have been taken which are length, external diameter, internal diameter, and weight by using vernier calliper, ruler, and analytical balance.

Figure 3-3: Tensile specimens

3.3.2 Universal Tensile Machine

Gedney (2002) stated that universal testers are the most usual testing machines, which test materials in tension, compression, or bending. To generate the stress-strain curve is their main function. After the diagram is created, a pencil and straight-edge, or a computer algorithm, may calculate yield strength, Young's modulus, tensile strength, or